Reprinted from "Electrical Engineer and Merchandiser," September, 1937.

Underground Cables for Trunk Telephone Lines--

with Special Reference to the Melbourne-Geelong Cable

By John Hill, B.Sc.
Chief Engineer's Branch,
Commonwealth Postmaster-General's Dept.

IN the early days of telephony, open wires were used for the transmission of speech, and for some years they were the only type of conductor suitable for use over other than very short distances. The first important step in providing cables suitable for speech transmission was taken in 1891 when the use of paper for insulating telephone cables was introduced, this enabling cables to be manufactured with a comparatively low electrostatic capacity per mile. Paper insulated cables were first used for subscribers' circuits, and it was soon found that, although a considerable improvement over gutta-percha insulated wire, as their length was extended both the loudness and clearness of the speech were impaired. For some time these effects were not clearly understood, as there had been no quantitative analysis of the effects on telephone transmission of the various electrical properties of the telephone circuit.

The foundations of a more exact conception of the principles of transmission were set out in papers published by Oliver Heaviside over a period of years beginning in 1882. The results of his calculations showed what effects under certain combinations of resistance, inductance and capacity could be expected on the propagation of the electromagnetic wave. Heaviside thus deduced that in transmitting speech over telephone circuits an improvement in transmission efficiency could be expected by adding inductance. This suggestion was taken up in America by Pupin and Campbell, who found that the insertion at regular and frequent intervals of highly efficient inductance coils, now called loading coils, greatly improved the transmission qualities of a circuit. A 20 lb. unloaded cable has an equivalent of 1.012 decibels per mile, whereas the same cable loaded with 88 mH. at intervals of 6,000 ft. has an equivalent of 0.371 decibels per mile, which means a cable nearly three times the length for the same overall attenuation. The far-reaching effects of the application of Heaviside's investigations to telephone transmission are an illustration of the importance of obtaining an accurate conception explained in mathematical form of the effect of various factors on a physical phenomenon.

The application of the loading principle led to great extensions of trunk cable systems in many countries. In the United States of America cables were laid between New York and Philadelphia, New York and New Haven, and Chicago and Milwaukee. In 1909 a severe sleet storm isolated Washington at the time of the inauguration of President Taft, and as a result the Bell System management determined to ensure against similar interruptions in future. An underground cable, including phantoms, was designed and laid in 1912 between Washington, Baltimore, Philadelphia and New York, and in 1913 was extended to Boston. It will be seen that even at this time the benefit of cable as a means of avoiding interruption to communication was realised.

At the same time the British post office had been carrying on a cable laying programme, and it is interesting to examine the details of the London-Birmingham loaded cable which was completed in 1915. This cable consisted of:—

2	pairs of	300	lb.	conductors
14	„ „	200	lb.	„
12	„ „	150	lb.	„
24	„ „	100	lb.	„

The coil spacing was 2½ miles, the coils for the side circuits being 135 mH., giving 54 mH. per mile loop. The loss over the full length, 125 miles, measured on completion, was 4.7 decibels for the 300 lb. circuits and 11.6 decibles for the 100 lb. circuits.

The next important factor in the development of long distance telephony after the introduction of loading was the use of telephone repeaters. It was found about 1912 that if a universal service for an entire country was to be realised, it would be necessary to find satisfactory means of amplifying the voice currents. Before this time attempts had been made to do this by means of so-called mechanical repeaters, and some of these were in use for a number of years. Fundamental difficulties of distortion, limits of gain, and instability led, however, to the gradual discontinuance of the use of these types of repeater.

Following on the work of various experimenters including Fleming and De Forest,

Paper presented before the Postal Electrical Society of Victoria, September 13, 1937.

improvements were gradually made in the application of thermionic tubes as amplifiers, and these were applied to telephone repeaters experimentally about 1913. The success of the application of repeaters to trunk circuits led logically to a great extension in the use of trunk cables, since it resulted in a very considerable increase in the distance over which satisfactory communication on cable circuits could be established.

A contrast to the London-Birmingham Cable laid in 1915 was the London-Glasgow cable, laid in 1925. This cable consisted of 88 pairs of 40 lb. conductors and 156 pairs of 20 lb. conductors, the side circuits being loaded with 177, 89 and 44 mH. coils at a spacing of 6,000 ft. The various weights of loading were used to provide circuits for various purposes, the heavier loading being used on the shorter lines. The 40 lb. conductors which were placed in the centre of the cable were used as two-wire circuits, and the 20 lb. conductors as four-wire circuits. The use of these light conductors, as compared with the 300 lb., 150 lb. and 100 lb. conductors of the 1915 London-Birmingham cable, was rendered possible by the development of efficient telephone repeaters.

Trunk cables with associated loading and amplification had now reached a high standard of efficiency, but further improvements were still desirable if good quality speech was to be transmitted over very long distances. The restrictions imposed by the use of loading coils upon the transmission of the higher frequencies and upon the speed of propagation, caused consideration to be given to a means of overcoming these disabilities. It had also been found that balance difficulties were associated with the use of telephone repeaters on a two-wire circuit which limited the gain that could be effectively used, and this was another difficulty to be overcome. Consideration was therefore given to the development of circuits that would be free from these drawbacks, and as a result the lightly loaded four-wire circuit was developed. This arrangement provides for using two transmission channels for each telephone circuit, each equipped to transmit speech in one direction only. As this system separates the two directions of transmission, balance is only required at the terminals of the circuit, making higher repeater gains possible and giving better transmission over the complete circuit.

With four-wire circuits crosstalk can be minimised by placing the transmitting pairs in a cable in one group and the receiving pairs in another group. This device was used in the London-Glasgow cable already referred to, and the principle has now been carried further by using separate cables for transmission in each direction. The four-wire system either in the same or separate cables is now in general use for long circuits.

A further development in trunk cable design occurred when it was found practicable and economical to work carrier systems over cables, and this system of operation is now being brought to a high degree of efficiency. In some countries single channel carriers have been in use over cables for a considerable period, and these were followed by a four-channel carrier system using frequencies up to 16 kc., this system being applied by the British post office to some existing cables when additional channels were required. In the meantime experiments were in progress in several countries in connection with multi-channel systems providing nine and 12 channels. The latter system has now been brought into operation in Great Britain and will be referred to later.

Where very large groups of channels are required and where, therefore, it would be economical to spend large amounts on equipment, it was realised that there were possibilities in the use of very high frequencies using a band of about 1,000,000 cycles worked over a coaxial cable, and investigations in this direction were begun.

Summarising, the following steps have taken place in the development of trunk cables:—

1. Rubber or gutta percha insulated wire used, having a high capacity; later used with a lead covering.
2. Paper insulated air space cables introduced on account of their lower capacity and therefore better transmission qualities.
3. Loading of cables with varying amounts of inductance.
4. Application of amplification by means of valve repeaters to cables, enabling smaller conductors and lighter loading with better transmission.
5. Widening of transmitted band of frequencies for effective speech over long circuits.
6. Development of four-wire circuits to provide for speech transmission over very long distances at higher velocities without echo and distortion effects.
7. Use of carrier circuits—single, four and 12 channel—over cable.
8. Coaxial cable with 1,000,000 cycle band width carrier superposed, providing for a very large number (200-300) of telephone channels.

Considerations Leading to Extended Use of Cable for Long Distance Communications

These may be briefly summarised under the following headings:—

1. General economic considerations.—At some point governed by the conditions along a route and the rate of development to be met, it becomes an economical proposition to lay a cable in lieu of adding open wires and/or carrier systems to the existing route. In comparing the costs of alternative methods of providing service,

attention must be given not merely to the initial capital outlay but to the total charges incurred over the life of the plant. It will sometimes be found that the scheme involving the highest initial capital outlay is really the most economical.

2. A cable has a lower average number of faults per circuit per annum than an open wire route, thus giving greater continuity of communication.

3. Circuits in a cable maintain their transmission characteristics much better than open wire circuits, and communication on a cable route is therefore kept at a more uniform standard. Carrier channels and repeaters used on open wire routes require changes in adjustment on account of variations in weather conditions, even during the one day.

4. Circuits in cable are not so susceptible to disturbance from outside electrical sources as are circuits on open wires.

5. In providing a cable, it is economical to lay down plant for a considerable period ahead, depending on the rate of development. This enables an unexpectedly rapid development to be quickly met, and seasonal fluctuations to be readily catered for, at all events until the cable is being used to its full capacity. In a cable plant there is, over a considerable portion of its life, a reservoir of circuits which may be of considerable service in meeting traffic requirements.

6. The cost of maintaining cables is generally much less than the cost of maintaining open wire circuits. The cost of complete working expenditure for the Commonwealth for the twelve months ended June 30,1936 were:—

Trunk wires in cables, 1/3 per wire mile.
Trunk aerial wires, £1/9/2 per wire mile.

7. Aesthetic considerations.—Whilst line engineers regard a well-constructed pole route as a thing of beauty, this view is not shared by everyone. Some people prefer trees to poles, and to them a cable out of sight appeals as a considerable advance over open wire construction.

The main considerations leading to the use of trunk cables have been indicated. It is the general experience in many parts of the world that the provision of the reliable, adequate and uniform circuits available in a cable results in a considerable increase in trunk traffic, and this experience has been borne out in Australia by the use made of the trunk service to Tasmania over the recently installed submarine cable link. The traffic in this case has greatly exceeded that anticipated, and is still steadily increasing.

Trunk Cables of Recent Date in Various Countries

Great Britain.—As recently as 1935 several large cables were laid in Great Britain intended for use as V.F. circuits, but providing for a considerable proportion of the pairs to also carry single-channel carrier systems. Among these were the Liverpool-Glasgow and London-Liverpool cables, which consisted of 270 pair 25 lb. conductors in star quad formation plus four screened 40 lb. pairs for broadcasting circuits. It was found after laying, that with suitable loading some pairs could be worked up to 16 kc, enabling four carrier channels in addition to the V.F. channel to be used, provided that repeaters were inserted at 30-mile intervals. Eight systems of this type giving 40 circuits have been installed over the Liverpool-Glasgow section. These circuits are worked on a four-wire basis. The loading consists of 120 mH. coils for voice frequency circuits, 22 mH. coils

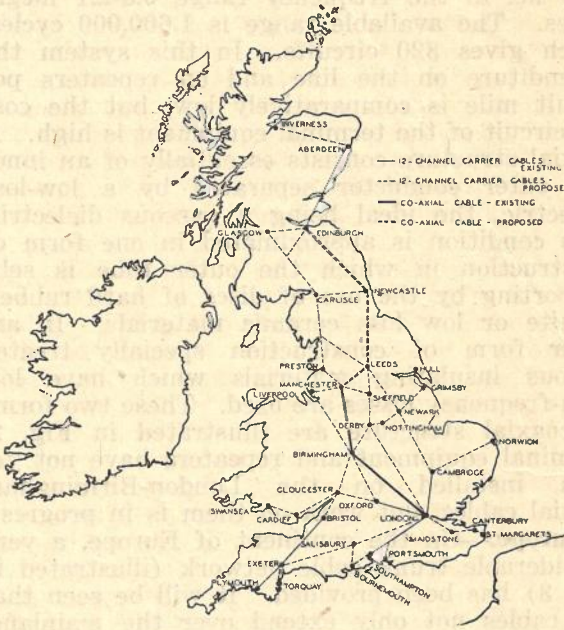


Fig. 1. Development of 12-Channel and Co-axial Systems in Great Britain

for single channel carrier circuits, 6 mH. coils for four-channel carrier circuits, and 16 mH. coils for broadcating circuits. The spacing adopted is 6,000 ft. for the first two and 3,000 ft. for the last two.

In 1935 the British post office decided to install between Bristol and Plymouth, a distance of 120 miles, a 12-channel system to operate over separate "go" and "return" unloaded cables, and this scheme has now been completed and is in operation.

Although the pair form of cable construction was adopted, it was found later that, for a given attenuation at 60 kc., a star quad cable can be designed that will occupy less space than a pair cable. A star quad cable containing 24 pairs of 40 lb. conductors has therefore been adopted as standard, and has been provided between London and Cambridge, London and Southampton, and Edinburgh and Aberdeen.

Plans have been prepared by the British post office which will result in a complete network of this type of trunk cable, with 12-channel carrier superposed, being provided within the next three years (see Fig. 1).

A four-tube coaxial cable with repeaters at an average distance of seven miles apart has been installed between London and Birmingham (125 miles). Its extension to Manchester is approaching completion, and it is proposed to extend it through Leeds to Newcastle. Two of the tubes are intended later for television, and the other two will be used for telephony, one for each direction of transmission. The equipment has been designed on the basis of spacing circuits at 5 kc. in the frequency range 0.5-2.1 megacycles. The available range is 1,600,000 cycles. which gives 320 circuits. In this system the expenditure on the line and on repeaters per circuit mile is comparatively low, but the cost per circuit of the terminal equipment is high. A coaxial structure consists essentially of an inner and outer conductor separated by a low-loss dielectric, the ideal being a gaseous dielectric. This condition is approximated in one form of construction in which the outer tube is self-supporting by the use of discs of hard rubber, ebonite or low loss ceramic materials. In another form of construction specially treated fibrous insulating materials which have low high-frequency losses are used. These two forms of coaxial structure are illustrated in Fig. 2. Terminal equipment and repeaters have not yet been installed on the London-Birmingham coaxial cables, but work on them is in progress.

Europe.—On the continent of Europe, a very considerable trunk cable network (illustrated in Fig. 3) has been provided. It will be seen that the cables not only extend over the mainland, but that submarine cable connects Great Britain to the system, and is also used to link Sweden and Norway with the remainder of the continent. To ensure satisfactory transmission over a trunk system which is installed and maintained by several administrations, a central advisory authority known as the Comite Consultatif International Telephonique, has been set up. This body, which consists of representatives of practically all countries in the world, prescribes not only desirable standards of transmission, but also suggests suitable means of attaining these standards. With the adoption of the standards laid down, a highly efficient trunk line communication system has been built up over the greater part of Europe, and is being added to and extended year by year.

In Germany the first commercial carrier on cable system was constructed in 1929 by Siemens and Halske and used on a submarine cable 100 miles long between Germany and Sweden. This was a single channel system worked on a four-wire basis. Recently a system has been developed in Germany called the L system which provides a four-wire single carrier channel in addition to a four-wire voice frequency channel over two pairs in a cable. One pair acts as the "go" and the other pair acts as the "return" for both the voice frequency and the carrier frequency. The band transmitted is from 300-5,700 cycles per sec., and not only the physical but the phantom circuits in a cable can be duplicated in this way.

A typical German cable consists of 218 pairs multiple twin. These are made up of a core and five layers, and include 34 pairs 50 lb. per mile and 172 pairs 20 lb. per mile, arranged in multiple twin formation, plus two screened 50 lb. pairs and 10 uncreened 20 lb. pairs, each of these pairs taking up the space of a quad and therefore having a lower capacity. These pairs are used for broadcasting or other special services. The 50 lb. conductors in quad formation are medium heavy loaded for two-wire operation, and the other quad 20 lb. conductors, are lightly loaded for four-wire operation. The total number of circuits derived, voice frequency and carrier, is 331.

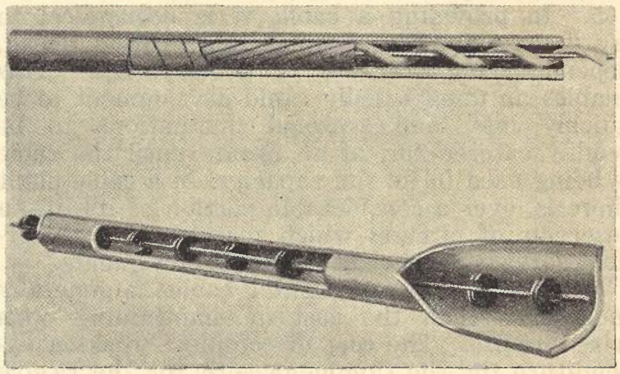


Fig. 2. Typical Co-axial Cables

Another system, also used in Germany over extra lightly loaded cable pairs, is called the "S" system. For this the low capacity pairs of 50 lb. conductors are loaded with 3.2 millihenry coils, giving a cutoff frequency of 20,000 cycles per sec. This allows for the use of three carrier channels in addition to the voice frequency channel. The usual spacing of repeaters for these systems is 45 miles. Experiments are proceeding in Germany with the use of a still larger number of carrier systems on one cable pair, but details of a commercial system are not yet available.

Coaxial cables have been laid in Germany recently, primarily for television purposes, but with the idea of the subsequent application of telephony over them. The intention is to use the band up to 1,000,000 cycles for telephony and above that for television. These cables are of the same general type already described.

The general conclusion reached in Germany at present is that there is a definite economic field for the use of wide band coaxial cables where it is required to provide for several hundreds of simultaneous conversations in the one group over long distances. There still, however, remains a large field for the use of other types of trunk cables.

Denmark.—In 1933 the Danish administration provided a tape-armored cable varying from 88 to 209 circuits between Aalborg and Kolding, a distance of about 135 miles. A typical section of this cable consisted of 46 pairs of 50 lb. conductors, 86 pairs of 20 lb. conductors and one lead covered 50 lb. pair in the centre of the cable for broadcasting. The loading on this cable, spaced at 6,000 ft., consisted mainly of 140 millihenry coils for two-wire and four-wire

Fig. 3. Main Trunk Cables of Europe

side circuits, and of 56 millihenry coils for the phantom circuits. Six of the pairs in each direction for four-wire working were, however, lightly loaded with 30 millihenry side and 12 millihenry phantom coils. The broadcasting pair was loaded with 16 millihenry coils.

The provision of a lead-covered pair in the centre of a cable, in addition to its use for broadcasting, has the obvious advantage that in most cases damage to the cable will not affect the lead-covered pairs, so that a good pair for fault location and for urgent communication is available. Such provision was given consideration in the case of some Australian cables, but the additional cost resulted in it being omitted.

Holland.—In 1931 the Dutch administration decided to introduce the four-wire system for all trunk circuits in Holland. At the same time they decided upon a loading standard of 65 mH. coils spaced 12,000 ft. apart as against their previous spacing of 6,000 ft. They claim that, under the conditions described, it is not necessary to use the more expensive trunk line type cable in which more rigid limits are specified in regard to capacity unbalance, but that a reasonably good quality subscribers' cable is quite satisfactory.

Between Amsterdam and Utrecht two cables were laid, each consisting of 210 pairs in star quad formation, having 16 lb. per mile conductors, with one screened pair for broadcasting programmes. The distance is about 30 miles. Five other trunk cables of the same type, of a total length of 200 miles, were also installed about this time and have since been added to. The effectively transmitted band width for this type of cable goes up to 2,800 cycles, and the velocity of propagation is high. This system with some small modifications to adapt it to Australian conditions is to be used between Melbourne and Geelong.

America.—In the United States of America the trunk cable network, a diagram of which is

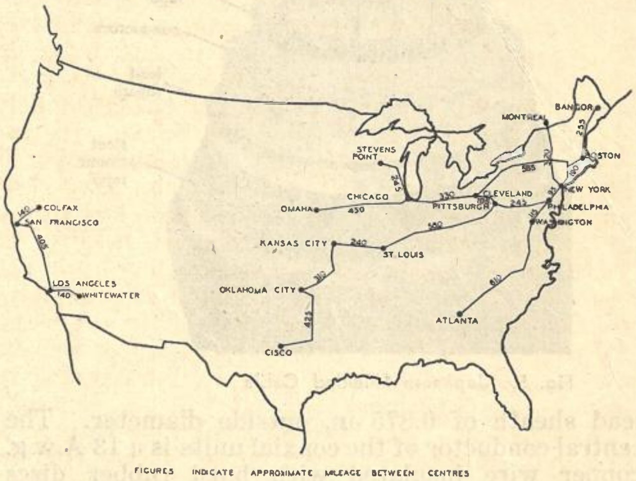


Fig. 4. Main Trunk Cables of America

shown in Fig. 4, has extended very rapidly, the percentage of trunk wire in cables increasing from 30 in 1915 to 82 in 1936. It consists of 27,000 miles of cable and 12,500,000 miles of conductor. The type of cable in general use is of multiple twin construction containing 20 lb. and 40 lb. quads with some unscreened 40 lb. pairs for broadcasting. In the United States, as in other countries, use is now being made of cables buried direct in the ground. These cables are in some cases protected only by layers of jute impregnated with asphaltum compounds, and in other cases a steel tape or wire armoring is added. Extensive experiments have been conducted in the United States in regard to the application of multichannel carrier systems to cable, and these are now being developed commercially.

An experimental coaxial cable has been installed between New York and Philadelphia, a distance of 95 miles. The system is equipped with eight intermediate repeaters at about 10 mile intervals, capable of handling a frequency band of 1,000,000 cycles, four being located in manholes. It is expected that this cable will provide 240 circuits. As a word of caution the writer of a recent article states, "Much work remains to be done before coaxial systems suitable for general commercial service can be produced."

The cable itself consists of two coaxial units, one "go" and one "return," each 0.265 in. inside diameter, together with four pairs of 20 lb. paper insulated wires, tne whole enclosed in a

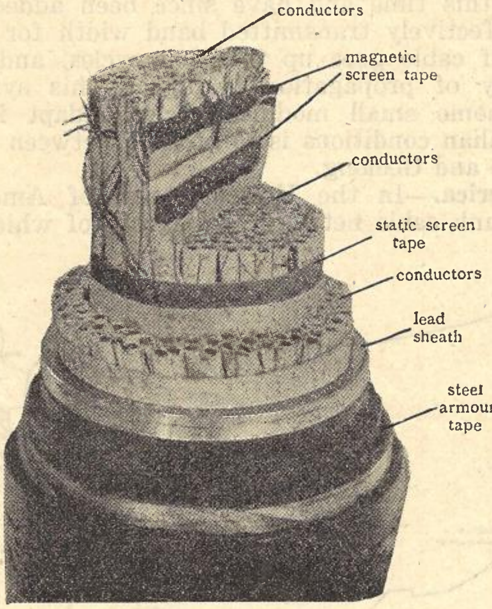


Fig. 5. Japanese Shielded Cable

lead sheath of 0.875 in. outside diameter. The central conductor of the coaxial units is a 13 A.w.g. copper wire insulated with hard rubber discs at intervals of $\frac{3}{4}$ in. The outer conductor is made up of nine overlapping copper tapes forming a tube 20 mils. thick, held together with a double wrapping of iron tape. So far as is known, only a portion of the terminal equipment has been provided, but it is understood that successful preliminary tests, one of which included a setup that was equivalent to operation over a circuit length of 3,800 miles, have been made.

Japan.—Two main trunk cable routes have been planned, one running along the Pacific coast and the other bordering the Sea of Japan, with submarine links between the islands. Various lateral routes are also proposed, connecting the two main routes at various points so that when the scheme is complete a cable network will be formed and communication will not be cut off by trouble at one point. A rapid increase in trunk cables in Japan, aerial, underground and submarine, took place between 1927 and 1934, the mileage of trunk cable increasing about fourfold during this period.

Until recently Japan used, for various purposes medium, light, or extra light loaded cables on the same basis as America and Europe, but in the last few years attention has been given by Japanese cable manufacturers and telephone companies to the provision of nonloaded cables suitable for carrier working. In nonloaded cables used at carrier frequencies, electromagnetic coupling between circuits becomes important, and it is for this reason that separate cables have been used for the "go" and "return" of such circuits.

A unique arrangement has been adopted in Japan to reduce crosstalk between four-wire circuits in the one cable by means of magnetic shields across the diameter of the cable dividing the circuits into two groups. Fig. 5 shows a 108-pair cable, nonloaded, provided with an annular static screen and a diametrical magnetic screen. The magnetic shield consists of an alloy tape 28 mm. by 0.1 mm. which has high permeability. The static shield is metallised paper. It is claimed that the use of this special alloy tape reduces the magnetic coupling between circuits in opposite directions to about 1/3 of its value without the shield.

Owing to the advantages claimed for nonloaded cable systems, projected extensions of the trunk cables of Japan are based on the use of nonloaded cable with carrier superposed worked on a four-wire basis. Work is in progress on the connection of Tokyo and Mukden (in Manchukuo) by cable, and a considerable length has already been completed. The distance is 1,700 miles, and the cable used is 28 pair star quad 1.4 mm. (about 50 lb.) conductors, 14 pairs being used for "go" circuits and 14 pairs for "return" circuits. The distance between repeater stations is 35 miles. It was decided that in some cases near repeater stations where the difference in levels was great it was advisable to use separate cables. This was particularly the case for the submarine section from Japan to Korea, where the length of repeater sections was determined by the presence of two islands giving distances of 58, 55 and 50 miles respectively between repeaters. In this case for the longest repeater section the arrangement made was:—From one terminal separate cables for $1\frac{1}{4}$ miles, electromagnetically shielded cable for $9\frac{1}{4}$ miles, electrostatically shielded cable for $35\frac{3}{4}$ miles, electromagnetically shielded cable again for $9\frac{1}{4}$ miles and twin cables for the last $2\frac{1}{2}$ miles, making a total distance of 58 miles.

On other parts of this route, and for other long distance cables in Japan, the practice adopted has been to use either separate cables or one magnetically shielded cable for about 1/3 of the distance on each side of a repeater station, and the middle one-third is filled by an electrostatically shielded cable. Over these cables three carrier channels and one voice channel are being provided on each complete four-wire cable circuit, that is, two pairs in the cable provide four-wire circuits, three at carrier frequency and one at voice frequency. The same carrier frequency is used in each direction. It is proposed later to increase the carrier channels to five or six.

Australia.—In Australia, no long distance trunk cables, other than the recent submarine link from Apollo Bay to Stanley, have yet been installed, although our statistical records show that there are 8,811 pair miles of underground cable used for trunk purposes. At the present time, however, several trunk cables are on order, the most important of which are as follows:—

Oakleigh to Dandenong cable, a distance of 11.6 miles, which will provide for linking up with the existing trunk cable from Central to Oakleigh and the elimination of all open wire construction between the trunk exchange in Melbourne and a point approximately a mile and a half on the country side of Dandenong, a total length of 22 miles. This cable includes 20 lb. and 40 lb. conductors, multiple twin type circuits, and screened and unscreened pairs. The cable will be unarmored, laid in ducts.

Townsville to Stewarts Creek.—This will consist of six miles of 38 pair 40 lb. tape armored star and quad type cable with short sections of submarine cable. As this cable will carry the main north coast trunk circuits between Brisbane-Townsville-Cairns as well as western trunks, Townsville-Cloncurry, provision has been made for single channel carrier loading with 13 mH. coils, and three channel carrier loading with 3.5 mH. coils, in addition to the voice frequency loading of 88/32 mH. coils.

Hobart-Longley.—This is a tape armored star quad cable 11 miles long partly 38 pair 40 lb. and partly 28 pair 40 lb. As no long distance circuits are associated with this cable, voice frequency loading only is used.

Tenders have also been received for the extension of the Adelaide to Epps Cross cable, 7 miles in length, to Salisbury, which is another 6 miles, making a total length of 13 miles, and just before this paper went to press tenders were invited for a trunk cable between Sydney, Newcastle and West Maitland, a distance of 122 miles.

Melbourne-Geelong Cable

The trunk cable from Melbourne to Geelong recently ordered by the postmaster-general's department will be the longest in Australia up to date, and it is confidently expected that not only will its installation considerably improve the trunk service between those places, but that it will result in a considerable increase in trunk line business over the route.

In considering the advisability of providing an underground cable between Melbourne and Geelong, close attention was given to the condition of the existing aerial route, and it was found that heavy expenditure would be required to place it in a condition to render completely satisfactory service and to provide for development. An economic study was then made of the whole problem and, after taking all factors into consideration, it was found that over a 20-year period the present value of all charges was:—

(a) For maintaining and adding to aerial route to meet development as required .. £174,000
(b) For installing a cable to meet same development £138,000

This showed an advantage of £36,000 in favor of the cable. Further studies were then made to determine the economic planning period for

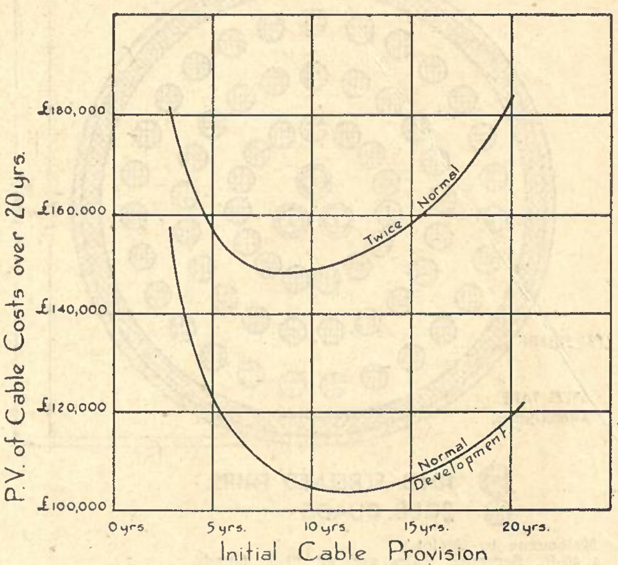
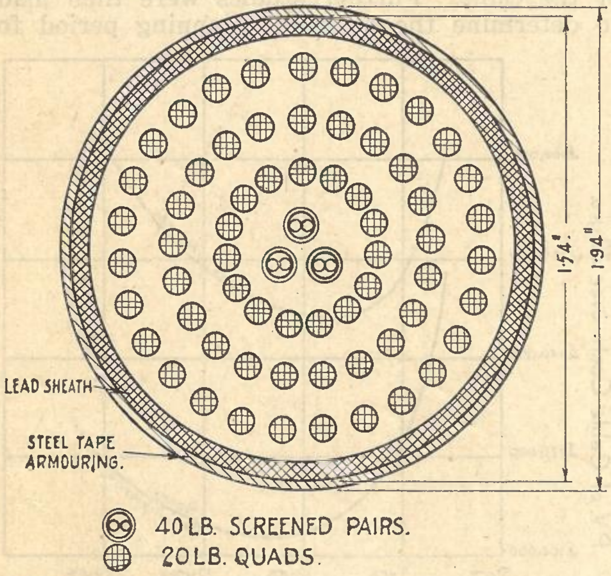


Fig. 6. Variation of Cable Costs with Planning Period

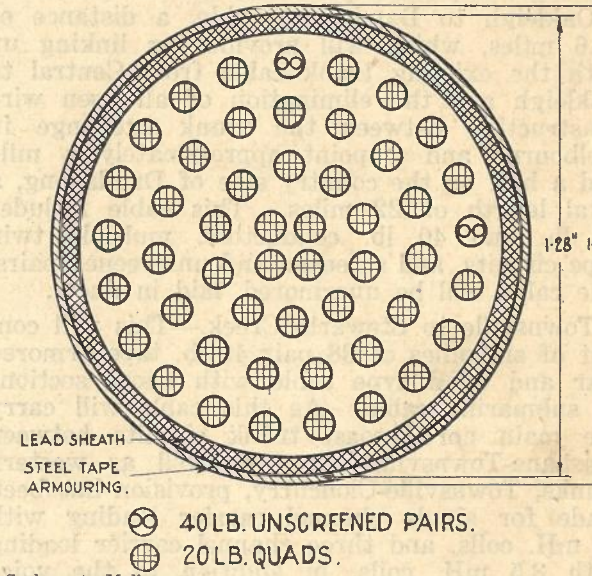
such a cable, and it is interesting to note firstly, that the economic planning period decreases with an increased rate of development, and secondly, that over a range of between 9-14 years for normal development the variation in overall cost is small (see Fig. 6). The decrease in the economic planning period with increased rate of development tends to compensate for any unexpected rise in the rate of development.

The road between Melbourne and Geelong is very suitable for the installation of an armored cable. It was therefore decided to call alternative tenders for armored and unarmored cable, and as a result of the prices quoted, armored cable was ordered, except for the portions in suburban areas and through townships where unarmored cable in ducts will be used. In the tenders received, eight different types of cable were offered, including one system incorporating the use of single channel carrier systems operated up to 5.7 kc. superposed on 50 lb. circuits loaded with 22 millihenry coils at 6,000 ft. spacing. In conjunction with the various types, several systems of loading were offered, ranging from 88 millihenry up to 176 millihenry coils for telephone side circuits with 16 millihenry coils for broadcasting pairs.

After detailed analysis of the systems offered, it was decided to adopt an arrangement providing for two separate local type star quad cables operating on a four-wire basis with all "goes" in one cable and "returns" in the other. The segregation of all circuits, with similar transmission levels at all points, in this manner appreciably reduces the required cross-talk limits necessary between pairs in comparison with either two or four-wire circuits in the one cable where high transmission level differences between circuits may occur. The advantage thus gained in the lower limit of crosstalk allowable between pairs is used in reducing the cost both in regard to the type of cable and subsequent jointing in relation to capacity unbalance conditions. The use of the two cables has also the important advantage of reducing the possibility of complete breakdown of service. Cross-sections of the two types of cable are shown in Fig. 7.



Melbourne to Geelong
3 40-lb. Screened Pairs and 63 20-lb. Quads



Geelong to Melbourne
2 40-lb. Unscreened Pairs and 48 20-lb. Quads

Fig. 7. Target Diagrams of the Melbourne-Geelong Cables

The additional pairs in the larger cable will be used principally for two-wire circuits from intermediate stations to Melbourne and Geelong. At both the Melbourne and Geelong ends, use will be made of existing cables, this being an eonomical arrangement until the wires in these cables are required for other purposes.

The loading will consist of:—

70 coil 88 mH. pots on each cable spaced at 9,000 ft. for the 20 lb. conductors;
4 coil 16 mH. pots spaced at 3,000 ft. for the 40 lb. broadcast pairs.

The amplifying equipment for the four-wire circuits will be installed at Melbourne and Geelong and will consist of single-stage pentode type high gain repeaters of the feed-back type. Forty repeaters are provided per bay, two bays being required at both Melbourne and Geelong. No intermediate repeaters are required at Werribee.

The types of broadcasting pairs provided in the two cables will enable an interesting comparison to be made between screened and unscreened pairs. The latter have a slightly higher mutual capacity, .085 mfd. per mile, as compared with .062 mfd. per mile, resulting in a slightly higher attenuation and a slightly lower cut-off frequency, and a lower guaranteed crosstalk attenuation to adjacent V.F. quads, 95 db. as compared with 110 db., whilst pair to pair crosstalk limits are the same. The unscreened pairs have the big advantage of being incorporated in the ordinary make-up of the cable with an appreciable reduction in overall diameter and saving in metal costs.

The total cost of the two cables will be approximately £61,000; of the loading, £9,000; and of the amplifying equipment, £4,000, making a total of £73,000 delivered. Adding an estimated installation cost of £12,000, the present capital cost of the work will be £86,000. This will be increased by another £9,000 for additional loading and equipment to be installed at some future date. After allowing for this, the cost, when the cable is in full use, will be about £19 per circuit mile.

It may be mentioned here that 60 per cent. of the cable is being made in Australia at the Port Kembla works of Metal Manufactures Ltd., and the remainder will be made by Standard Telephones and Cables Ltd. in Great Britain. The latter firm is also supplying the loading and equipment.